

1 SYSTEM AND METHOD FOR RAPIDLY
2 IDENTIFYING PATHOGENS, BACTERIA AND ABNORMAL CELLS
3

4 CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims the benefit of commonly
6 owned and copending U.S. Provisional Application Serial
7 Nos. 60/458,769, filed March 27, 2003, and 60/505,944,
8 filed September 25, 2003.

9
10 TECHNICAL FIELD

11 The present invention generally relates to a system
12 and method for identifying pathogens and abnormal cells.
13

14 BACKGROUND ART

15 The timely diagnosis of pathogens, bacteria,
16 abnormal cell and infectious diseases is often
17 complicated by the need to use cultures as the means to
18 identify the bacteria and select the optimum treatment.
19 Currently, identification of pathogens often takes days
20 and involves complicated procedures, a situation that may
21 unduly delay effective treatment such as the appropriate
22 selection of an optimal antibiotic. Similar problems
23 exist in detecting bacterial contamination in food,
24 especially in beef, poultry and fish. The delay in
25 identifying the presence of harmful bacteria in food

1 products could result in contaminated products being
2 released for distribution and consumption with dire
3 consequences. In some instances, these delays have
4 proved to be fatal to patients or have caused unnecessary
5 suffering. According to 1999 statistics provided by the
6 Center for Disease Control, there were 1,194,959 reported
7 cases of infectious diseases caused by bacteria.
8 Furthermore, there were many instances of food poisoning
9 that were not subject to mandatory reporting to the
10 Center for Disease Control. A common practice in
11 treating infected patients is the use of broad-spectrum
12 antibiotics. However, due to the problem of bacterial
13 resistance to many antibiotics, broad-spectrum
14 antibiotics may not be effective. Many of these cases of
15 infectious diseases could have been prevented or promptly
16 treated if rapid and accurate diagnosis was available.
17 Rapid identification of pathogens, bacteria and abnormal
18 cells is also critical in dealing with bio-terrorism and
19 with biological agents during warfare.

20

21 DISCLOSURE OF THE INVENTION

22 The present invention achieves rapid identification
23 of pathogens, bacteria and other abnormal human and
24 animal cells. In one embodiment, the present invention

1 is directed to a non-invasive system and method for
2 automatically and rapidly identifying pathogens. In
3 accordance with one embodiment of the invention, the
4 system comprises a first subsystem that obtains and
5 processes images of specimens of pathogens, bacteria or
6 other abnormal cells, and a second subsystem that accepts
7 the images of the specimens, isolates the particular
8 features of each image using advanced image segmentation,
9 and then rapidly and accurately identifies the pathogens,
10 bacteria or abnormal cell structure using pattern
11 recognition processing on the particular isolated
12 features.

13 In one embodiment, the first subsystem described in
14 the foregoing description comprises an image capturing
15 system that comprises a microscope and a video camera.
16 The image capturing system captures or acquires an image
17 of a specimen of a pathogen, bacteria or abnormal cell
18 structure, and then enhances, digitizes and temporarily
19 stores the pertinent parts of the captured or acquired
20 image of the specimen. The first subsystem further
21 comprises a communication system that transmits the
22 processed image to the second subsystem via any one of a
23 variety of suitable communication schemes such as
24 satellite links, the Internet, or telephone lines. In a

1 preferred embodiment, the first subsystem further
2 includes a computer, microprocessor or other controller
3 to control the operation of the first subsystem. In a
4 preferred embodiment, the first subsystem is configured
5 to have automatic operation so as to minimize the manual
6 effort in processing the image of the specimens.

7 In one embodiment, the second subsystem is typically
8 located at a central location. The second subsystem
9 receives the processed image transmitted by the first
10 subsystem. The second subsystem comprises an image
11 processing system that processes the images received from
12 the first subsystem so as to isolate certain features of
13 the image of the specimens that are of interest. This
14 image processor effects image segmentation to isolate the
15 aforementioned features of the image. The second
16 subsystem comprises a database that contains known
17 reference images. Such a data base functions as a
18 library of images of known pathogen cells, bacteria cells
19 and abnormal cells. Each reference image is associated
20 with a known pathogen, bacteria or abnormal cell
21 structure. The image processing system implements a data
22 mining program that extracts particular image data from
23 the isolated features and a pattern recognition program
24 that compares the extracted image data to the known

1 reference images in the database in order to determine if
2 the isolated feature corresponds to or matches any of the
3 known reference images.

4 The system and method of the present invention can
5 also be used as a diagnostic radiology and imaging tool
6 in the medical and dental field. Specifically, the
7 system and method of the present invention can be
8 configured to analyze medical images such as images of
9 soft tissue, mammograms, x-rays (bone and dental),
10 ultrasounds, MRI images, and CAT scans.

11 In another embodiment, the system is configured so
12 that the first subsystem and second subsystem are joined
13 together to form one main system that is located at one
14 location. Such a configuration would be suitable for a
15 large city hospital or one of the many teaching hospitals
16 in the United States and throughout the world.

17 Thus, the present invention is directed to, in one
18 aspect, a method for identifying pathogens, comprising
19 providing an image, processing the provided image with an
20 image segmentation algorithm to isolate at least one
21 segment of the provided image that has a feature that is
22 of interest, and comparing the isolated segment of the
23 provided image to a plurality of reference images to

1 determine if the isolated segment corresponds to any of
2 the reference images.

3 In a related aspect, the present invention is
4 directed to a system for identifying pathogens,
5 comprising a device to provide an image, a data base
6 having at least one reference image stored therein, and
7 an image processing resource to (i) process the provided
8 image with an image segmentation algorithm to isolate at
9 least one segment of the provided image that has a
10 feature of interest, and (ii) to compare the isolated
11 segment of the provided image to the reference image to
12 determine if the isolated segment corresponds to the
13 reference image.

14

15 BRIEF DESCRIPTION OF THE DRAWINGS

16

17 The features of the invention are believed to be
18 novel. The figures are for illustration purposes only
19 and are not drawn to scale. The invention itself,
20 however, both as to organization and method of operation,
21 may best be understood by reference to the detailed
22 description which follows taken in conjunction with the
23 accompanying drawings in which:

24 FIG. 1 is a block diagram of the system of the

1 present invention.

2 FIG. 2 is a perspective view of one embodiment of an
3 imaging subsystem shown in FIG. 1.

4 FIG. 3 is a perspective view of the rear side of the
5 imaging subsystem of FIG. 2.

6 FIG. 4 is a flow chart illustrating the operation of
7 the imaging subsystem shown in FIG. 1.

8 FIG. 5 is a block diagram of an image management
9 diagnostic subsystem shown in FIG. 1.

10 FIGS. 5A-5D show a flow chart illustrating the
11 operation of the image management diagnostic subsystem
12 shown in FIG. 5.

13 FIG. 6 is a flow chart illustrating a cluster
14 scheduling process used by the image management
15 diagnostic subsystem shown in FIG. 5.

16

17 MODES FOR CARRYING OUT THE INVENTION

18

19 Referring to FIG. 1, there is shown a block diagram
20 of a system for rapid identification of pathogens,
21 bacteria and abnormal cell structures in accordance with
22 the invention. System 100 generally comprises imaging
23 subsystem 100a and image management diagnostic subsystem
24 100b. Subsystem 100a generally comprises computer or

1 controller 101, staining module 102, microscope 104,
2 digital color video camera 106, image memory 108 and
3 communications module 110. As will be apparent from the
4 ensuing description, computer 101 controls the operation
5 and the sequence of operation of microscope 104, digital
6 color video camera 106, image memory 108 and
7 communications system 110.

8 Referring to FIG. 1, staining module 102 stains the
9 slides of specimens of pathogens, bacteria and abnormal
10 cells that are affixed to slides. The slides are stained
11 prior to being viewed with microscope 104. In a
12 preferred embodiment, staining module 102 is a
13 commercially available immune staining procedures module.
14 One such suitable commercially available immune staining
15 procedures module is known in the art as motorized
16 fluorescence filters for accurate color imaging of the
17 stained cells. In a preferred embodiment, between five
18 and ten different stains are selected to stain a
19 predetermined number of slides for a given specimen in
20 order to ensure that at least one of these slides has a
21 pathogen, bacteria or abnormal cell stained to produce an
22 acceptable image.

23

24

1 In one embodiment, statistical analysis is used to
2 determine a sufficient number of specimen slides that are
3 needed to ensure that at least one of the slides contains
4 the offending pathogen, bacteria, etc. Staining module
5 102 is configured to utilize a standard set of stains to
6 cover the range of pathogens, bacteria, etc. of interest.

7 Referring to FIG. 1, microscope 104 is configured to
8 provide sufficient magnification and includes an oil
9 immersion objective, an optical port for video camera
10 106, an auto stage mechanism, and an auto focus
11 mechanism. The auto stage mechanism comprises a shallow
12 well for the convenient placement of the specimen slides.
13 The automatic stage mechanism performs a raster scan of
14 each slide while the auto focus mechanism maintains the
15 image in focus. The auto stage mechanism is configured
16 to stop briefly at each step to allow an image to be
17 acquired. Each acquired image is assigned the x-y
18 coordinates of the position of the auto stage mechanism.
19 These x-y coordinates are automatically added in an
20 appropriate format to the acquired image of the specimen.

21 Referring to FIG. 1, video camera 106 is controlled
22 by computer or controller 101 to capture or acquire a
23 color image of the specimen at each stop of the auto
24 stage mechanism of microscope 104. Video camera 106 is

1 configured to provide adequate resolution and stability.
2 Video camera 106 digitizes the acquired image. The
3 digitized image is then transferred to image memory 108.
4 Image memory 108 is a temporary memory having sufficient
5 data storage capacity to temporarily store the acquired
6 images generated by video camera 106.

7 In a preferred embodiment, microscope 104 and video
8 camera 106 are realized as a single, commercially
9 available compact unit which combines the functions of
10 both microscope 104 and video camera 106. One such
11 commercially available unit is the Leica Model DMRXA2
12 Microscope. Other suitable, commercially available
13 devices that combine a microscope and video camera into a
14 single unit may be used as well.

15 In an alternate embodiment, the acquired images are
16 pre-screened and presorted for useful and relevant
17 content. This is accomplished by a screening processor
18 and display device (both of which not being shown) that
19 is in electronic data communication with image memory
20 108. This pre-screening and presorting function ensures
21 that further analysis is performed only on images having
22 relevant information. The screening processor utilizes
23 predetermined criteria (descriptors) to determine whether
24 the images have relevant content.

1 Referring to FIG. 1, computer 101 controls image
2 memory 108 to transfer stored digitized images into
3 communications module 110. In one embodiment,
4 communications module 110 includes RF (radio frequency)
5 antenna 111. However, communications module 110 is
6 preferably configured to transmit the digitized images to
7 second subsystem 100b via any one of a variety of
8 suitable communications modes, e.g. telephone lines, the
9 Internet, dedicated lines or RF communication or
10 communication through satellite communication. In
11 accordance with the invention, the communications link
12 between first subsystem 100a and second subsystem 100b is
13 bi-directional. In a preferred embodiment, the
14 communication between first subsystem 100a and second
15 subsystem 100b is real time. In one embodiment,
16 communications module 110 is realized as a DSL
17 Speedstream Model 5260.

18 In a preferred embodiment, a suitable, commercially
19 available PC (personal computer) high end system is used
20 to realize control module 101 and image memory 108.

21 In an alternate embodiment, subsystem 100a can be
22 realized by separate, suitable commercially available
23 components. For example, microscope 104 can be realized
24 by a suitable, commercially available electronic or

1 digital microscope. Similarly, video camera 106 can be
2 realized by a suitable video camera that can provide a
3 color image based on the image provided by the digital
4 microscope.

5 Referring to FIGS. 2 and 3, there is shown imaging
6 subsystem 100a in accordance with an alternate embodiment
7 of the invention. In this embodiment, all the components
8 of subsystem 100a are combined into a single unit that is
9 portable, compact, robust, and capable of battery-power
10 operation or AC power to allow for mobile operation or
11 operation in remote locations. This embodiment of image
12 subsystem 100a has housing 120, control panels 122 and
13 123, and interface 124. Interface 124 comprises RS 232
14 interface 126, video data ports 128 and 130, USB port 132
15 and external power input 134. Rechargeable battery pack
16 136 supplies power to all other components. Screen 138
17 allows capture of air samples that are to be analyzed
18 thereby allowing airborne pathogens, bacteria, etc. to be
19 analyzed. Slide insertion device 140 enables a user to
20 insert a specimen slide 142 into housing 120. Fluid
21 inlet 144 and fluid outlet 146 allow for the ingress and
22 egress of fluids (e.g. water) that is to be analyzed. In
23 an alternate embodiment, the particular embodiment of
24 subsystem 100a shown in FIGS. 2 and 3 is configured to

1 operate with power from a land vehicle's battery.

2 Referring to FIGS. 1 and 4, there is shown a flow
3 chart illustrating the operation of imaging subsystem
4 100a. In step 150, a user activates computer 101. In
5 step 152, any required data stored in a master system
6 (not shown) is loaded into computer 101. In step 154,
7 there occurs the development of the sample or specimen,
8 preparations and protocols. In this step, the specimen
9 is stained by staining module 102. In step 156,
10 microscope 104 and video camera 106 are activated by
11 computer 101, and a stained specimen slide is provided to
12 microscope 104. Next, in steps 158, 160 and 162, it is
13 determined whether the imaging of the specimen slides is
14 going to be controlled manually (i.e. locally). If it is
15 decided that there will be manual control, the user
16 inputs manual input commands into computer 101 in order
17 to control microscope 104 and video camera 106 according
18 to the data defined by such commands. Next, in step 164,
19 an image of the specimen is produced. In step 166, the
20 produced image of the specimen is displayed on an
21 external display device (not shown) such as computer
22 screen or LCD which may be connected to either computer
23 101 or video camera 106. Included in steps 164 and 166
24 are the steps of pre-screening and pre-sorting of the

1 images in order to determine if the image contains
2 relevant information. In one embodiment, medical
3 personnel pre-screen the images by visual inspection. In
4 step 168, the relevant images are collected and organized
5 in image memory 108. In step 170, the relevant images
6 are stored in image memory 108 or in an external data
7 storage device (not shown) such as a ROM or CD-ROM. In
8 one embodiment, the external data storage device is an
9 external device that is in electronic data communication
10 with image memory 108. In step 172, the relevant
11 collected and organized images are sent to an output
12 buffer memory and then, routed to communications module
13 110. In step 174, these images are then communicated to
14 image management diagnostic subsystem 100b with
15 communication module 110.

16 Referring to FIG. 1, in one embodiment of the
17 invention, image management diagnostic subsystem 100b is
18 centrally located. In a preferred embodiment, subsystem
19 100b is configured to serve a plurality of subsystems
20 100a and provide diagnosis information in near real time.
21 Subsystem 100b generally comprises communications module
22 180, antenna 181, temporary image memory 182 and image
23 processing system 190. Communications module 180
24 receives the digitized image data transmitted by

1 communications module 110 of subsystem 100a. In one
2 embodiment, communications module 180 is realized by the
3 commercially available DSL Speedstream Model 5260
4 described in the foregoing description. This received
5 digitized image data is then transferred to temporary
6 image memory 182. The stored digitized image is then
7 transferred from temporary image memory 182 to image
8 processing system 190. Referring to FIG. 5, there is
9 shown a block diagram of image processing subsystem 190.
10 Image processing system 190 comprises work stations 200,
11 202 and 204 which are in electronic data communication
12 with common hub 206. In one embodiment, work stations
13 200, 202 and 204 are commercially available Pentium™
14 class computers which are manufactured by Linux™, Sun™,
15 and Microsoft™, respectively. In one embodiment, common
16 hub 206 is configured as a commercially available switch
17 such as a Hewlett Packard or compatible 10/100/1000 hub.
18 Image processing system 190 further comprises master node
19 208 and firewall 210 between master node 208 and common
20 hub 206. Master node 208 comprises data processing
21 modules that effect implementation and execution of the
22 particular image processing and analysis computer
23 programs that are described in the ensuing description.
24 In a preferred embodiment, master node 208 is configured

1 to implement high-speed parallel processing. In one
2 embodiment, master node 208 comprises a Scyld Beowulf
3 Computer Cluster which has a parallel processor
4 comprising 64 nodes. The Scyld Beowulf Computer Cluster
5 is known in the art and was developed by the NASA Goddard
6 Space Flight Center. Image processing subsystem 190
7 further comprises central hub 212. In one embodiment,
8 central hub 212 is configured as a commercially available
9 switch such as a Hewlett Packard or compatible
10 10/100/1000 hub. Image processing subsystem 190 further
11 comprises a plurality of slave nodes 214 that are in
12 electronic data communication with central hub 212. In
13 one embodiment, there are sixty-four slave nodes 214 and
14 each slave node 214 is configured as a PC Pentium class
15 computer having a minimum of 128 MB of RAM. Image
16 processing system 190 further comprises database server
17 220. Database server 220 stores the image data that
18 originated from subsystem 100a (see FIG. 1) and which is
19 to be analyzed by subsystem 100b. Data base servers are
20 known in the art and need not be discussed herein in
21 detail. Image processing system 190 further comprises
22 file server image repository 222 which has sufficient
23 data storage capacity. Repository 222 has first and
24 second sections. The first section is for storing images

1 of known pathogens, bacteria and abnormal cells.
2 Specifically, the first section contains a large library
3 of reference images of pathogens, abnormal cell
4 structures, bacteria, etc. with several different views
5 of each type to account for rotation and other apparent
6 differences. Preferably, the referenced images are
7 compressed to minimize the memory requirements. Each
8 reference image has corresponding identification
9 information that provides information about the reference
10 image such as the name of the pathogen, bacteria, cell,
11 etc. The second section of repository 222 is for the
12 storage of segments of images produced by a hierarchical
13 segmentation process that is described in the ensuing
14 description.

15 Referring to FIGS. 1 and 5, images outputted by
16 temporary image memory 182 are inputted into database
17 server 220. Images in database server 220 are routed to
18 master node 208 by using any of the workstations 200, 202
19 and 204. Master node 208 performs several functions.
20 Master node 208 performs a pre-scan of the digitized
21 images received from database server 220 to determine if
22 the digitized images contain relevant and useful
23 information. If the images do not contain relevant and
24 useful information, the images are either discarded (i.e.

1 deleted) or stored in a designated area in file server
2 image repository 222. If the images do contain relevant
3 and useful information, the images are then subjected to
4 further processing. Specifically, master node 208
5 performs segmentation on the image. In one embodiment,
6 master node 208 is programmed to execute a segmentation
7 process described in pending U.S. patent application
8 serial number 09/839,147 entitled "Method For
9 Implementation Of Recursive Hierarchical Segmentation On
10 Parallel Computers", the disclosure of which is
11 incorporated herein by reference. The aforementioned
12 pending U.S. application serial number 09/839,147 was
13 published on May 1, 2003 having Patent Application
14 Publication No. US 2003/0081833. Publication No. US
15 2003/0081833 is incorporated herein by reference. The
16 segmentation process isolates particular features of the
17 digitized image. Specifically, this segmentation process
18 effects a sequential set of image segmentations at
19 different levels of segmentation detail in which the
20 segmentations at a relatively coarser level of detail is
21 produced from simple mergers of regions from
22 segmentations of finer levels of detail. A unique
23 feature of the hierarchical image segmentation process is
24 that the segmented region boundaries are maintained at

1 the full image spatial resolution at all levels of
2 segmentation details in the hierarchy. The result of the
3 process is that regions of similar characteristics are
4 isolated (segmented) and identified. Thus, the image of
5 a pathogen that has features distinct from the background
6 and debris can be isolated using certain assigned
7 criteria, e.g. color, shape, size, etc.

8 Master node 208 then performs a fast analysis on the
9 isolated feature based on a few descriptors such as size
10 and shape of the isolated feature. Master node 208
11 includes a memory for storing criteria that is used in
12 the fast analysis to determine whether or not a
13 particular image of an isolated feature has useful
14 information. If the particular image has useful
15 information, the particular image is retained and made
16 available for further analysis. If it is determined that
17 the particular image does not have useful information,
18 the particular image is discarded. If a particular image
19 of an isolated feature does have useful information,
20 master node 208 performs further processing on that
21 image. Specifically, master node 208 implements and
22 executes a computer program that effects optical
23 recognition and data mining. In one embodiment, this
24 computer program is configured as the computer program

1 referred to as "Continuously Scalable Template Matching"
2 developed by NASA Jet Propulsion Laboratories and
3 CalTech. This computer program comprises a first portion
4 that effects data mining and a second portion that
5 effects optical recognition. The data mining portion is
6 configured as the computer program known as "Diamond Eye"
7 which is known in the art and developed by NASA's Jet
8 Propulsion Laboratory. The "Diamond Eye" computer
9 program is based on a distributed applet/server
10 architecture that provides platform-independent access to
11 image mining services. A database associated with
12 "Diamond Eye" computer program provides persistent
13 storage and enables querying of the "mined" information.
14 The computational engine carries out parallel execution
15 of the most demanding parts of the data-mining task:
16 image processing, object recognition, and querying-by-
17 content operations. The purpose of the data mining
18 process is to extract desired, particular image data from
19 the isolated feature or features of the subject image
20 that result from the segmentation process described in
21 the foregoing description. The user inputs particular
22 data that defines the parameters of the image data that
23 is to be mined from the isolated feature or features of
24 the subject image.

1 The optical recognition portion of the computer
2 program executed by master node 208 comprises a pattern
3 recognition program that determines whether the mined
4 data obtained by the data mining portion of the computer
5 program matches or corresponds to any reference images in
6 the reference library portion of file server image
7 repository 222. The optical recognition program can
8 detect patterns that differ in size but are otherwise
9 similar to a specified (reference) pattern. If a match
10 or correspondence exists, the reference image, the
11 subject isolated feature which matches or corresponds to
12 the reference image, and any information associated with
13 the reference image, are displayed on the displays of
14 work stations 200, 202 and 204. Master node 208 also
15 effects execution and implementation of an image analysis
16 program that performs statistical analysis on the subject
17 isolated feature to identify areas of interest which aids
18 medical personnel in making a diagnosis. One suitable
19 image analysis program is the ImageJ program developed at
20 the National Institute of Health. As a result, medical
21 personnel can make a diagnosis upon viewing the resulting
22 information at any of work stations 200, 202 and 204. If
23 there is no matching or corresponding reference image for
24 a subject isolated feature, then such information is

1 displayed at work stations 200, 202 and 204.

2 Master node 208 also implements and executes a
3 scheduling program, described in detail in the ensuing
4 description, which effects cost and time efficient
5 scheduling of all of the nodes of image processing system
6 190. Thus, whether there are 16, 64 or 128 nodes in
7 image processing system 190, the nodes will be used
8 efficiently to achieve optimum operation in a cost
9 efficient manner.

10 Referring to FIGS. 5A-5D, there is shown a flow
11 chart of the image processing method implemented by image
12 processing system 190. The method starts in step 300
13 upon a command inputted by a user into any of work
14 stations 200, 202 and 204. In step 302, a user uses any
15 of the work stations 200, 202 and 204 to retrieve an
16 image from database server 220. The image retrieved is
17 the image that is to be processed and analyzed by master
18 node 208. As described in the foregoing description, the
19 retrieved image can be in JPEG, TIFF or other format. In
20 step 304, master node 208 converts the retrieved image
21 into raw data that is suitable for processing by master
22 node 208. In step 306, the user may input commands into
23 work stations 200, 202 and 204 such as parameter data and
24 recursive level data for use by the hierarchical

1 segmentation process implemented by master node 208. The
2 parameter data includes the number of regions in which
3 the subject image is to be divided. Each region defines
4 a specific portion of the image in which medical
5 personnel are interested in analyzing. The recursive
6 level data defines the desired bit resolution and the
7 bandwidth required to process the images. In an
8 alternate embodiment, the parameter data and recursive
9 level data are not inputted by the users but rather, are
10 preset within the software. Next, step 307 effects
11 implementation of a cluster scheduling program that
12 schedules use of the clusters within master node 208 in
13 order achieve time and cost efficient operation and use
14 of the clusters. Thus, step 307 ensures that all
15 clusters are always performing tasks at any given moment
16 and that no clusters are idle. Step 307 also schedules
17 time and efficient operation and use of file server image
18 repository 222 and database server 220. The scheduling
19 program is described in the ensuing description. Next,
20 in step 308, it is determined if the method is to proceed
21 with the hierarchical segmentation process. If the
22 method is not to proceed with hierarchical segmentation,
23 then the method ends at step 309. If the method is to
24 proceed with hierarchical segmentation, the method

1 proceeds to steps 310, 312 or 314. Step 310 determines
2 whether the retrieved image shall be formatted into RGB
3 (Red, Green, Blue) format prior to the retrieved image
4 being segmented by hierarchical segmentation. If RGB
5 format is desired, the method shifts to step 318 wherein
6 the hierarchical segmentation process begins. If RGB
7 format is not desired, the method shifts to step 312. In
8 step 312, it is determined whether the retrieved image
9 shall be formatted into eight (8) bit format prior to the
10 retrieved image being segmented by hierarchical
11 segmentation. If eight (8) bit is desired, the method
12 shifts to step 318 wherein the hierarchical segmentation
13 process begins. If eight (8) bit format is not desired,
14 the method shifts to step 314. In step 314, it is
15 determined whether the retrieved image shall be formatted
16 into sixteen (16) bit format prior to the retrieved image
17 being segmented by hierarchical segmentation. If sixteen
18 (16) bit format is not desired, then the method shifts to
19 step 315 which resets the parameters. The method then
20 shifts to step 316 which causes the method to return to
21 the beginning, step 300. If sixteen (16) bit format is
22 desired, the method shifts to step 318 wherein the
23 hierarchical segmentation process begins. As is apparent
24 from the foregoing description, the decision process

1 performed by steps 310, 312 and 314 depends upon the
2 recursive levels inputted in step 306. In step 318, the
3 hierarchical segmentation process begins and breaks the
4 retrieved image into segments. Each segment defines a
5 particular region of the retrieved image (retrieved in
6 step 302). In step 320, it is determined whether the
7 segments are to undergo further processing or whether the
8 segments are to be stored in repository 222. If step 320
9 determines that the segments of the particular regions
10 are not to undergo further processing, then step 322
11 effects storage of these images of the particular regions
12 in repository 222. If step 320 determines that the
13 segments are to undergo further processing, then the
14 method shifts to step 324 wherein the regions defined by
15 the segments are mapped. Specifically, step 324 effects
16 mapping or assignment of labels to each region. In step
17 325, the labeled regions are stored in repository 222.

18 Next, in step 326, the users input data defining
19 desired CSTM (Continuously Scalable Template Matching)
20 models into master node 208 via any of the work stations
21 200, 202 and 204. Specifically, this data defines the
22 desired models that are to be created based on the
23 reference images stored in image repository 222. These
24 models are based on specific features and characteristics

1 of certain pathogens, bacteria or other disease. Next,
2 step 327 then determines if the CSTM models exist in the
3 labeled regions stored in repository 222. This step is
4 accomplished by execution of the "Continuously Scalable
5 Template Matching" program described in the foregoing
6 description. If the CSTM models do not exist in the
7 labeled regions stored in repository 222, then the method
8 shifts to step 328 which sends data to work stations 200,
9 202 and 204 that indicates that no match has been found.
10 If step 327 determines that there are CSTM models that
11 match or correspond to labeled regions stored in
12 repository 222, then the method shifts to step 330 which
13 effects retrieval of the labeled images defining the
14 particular region or regions to which the CSTM model or
15 models correspond. In step 332, the retrieved labeled
16 images are displayed at work stations 200, 202 and 204 so
17 as to enable medical personal to review the retrieved
18 image and make a diagnosis. The method then ends at step
19 334.

20 Referring to FIG. 6, there is shown a flow chart of
21 the cluster scheduling program of step 307. In step 400,
22 it is determined whether the cluster scheduling program
23 is to be executed. If the cluster scheduling program is
24 not to be initiated, the cluster scheduling program is

1 terminated and the method implemented by master node 208
2 shifts to step 308 (see FIG. 5A). If the cluster
3 scheduling program is to be executed, then the program
4 shifts to step 402. Step 402 determines the number of
5 nodes that are being requested to process the subject
6 images. Thus, step 402 determines if four (4), sixteen
7 (16), sixty four (64), one hundred twenty (128) or more
8 nodes are requested. In step 404, it is determined if
9 fast nodes or slow nodes are being requested for
10 processing the subject retrieved images. Whether fast or
11 slow nodes are used depends upon the amount of images to
12 be processed and the time factors dictated by any
13 particular situation, e.g. emergency, chemical warfare
14 scenario, etc. In step 406, it is determined whether
15 there will be a time delay associated with any of the
16 required nodes. Specifically, step 406 determines if
17 there will be a time delay before particular nodes are
18 available for processing the subject retrieved image.
19 The time delay is the amount of time needed by that node
20 to complete its other task. Thus, if a particular node
21 is busy on another task, master node 208 will schedule
22 that node to be used for processing the subject retrieved
23 image upon expiration of the amount of time needed by
24 that node to complete its other task. Similarly, master

1 node 208 schedules nodes to commence new tasks upon
2 completion of the current tasks. Whether there will be
3 time delays depends upon many factors such as the
4 recursive levels, the desired number of nodes, and
5 whether fast or slow nodes are required. Next, step 408
6 calculates the cost factor for this particular processing
7 task. The cost function depends upon the recursive
8 levels, the desired number of nodes, whether the fast or
9 slow nodes are required, and any time delays. Thus, the
10 cost factor can be varied if any of these preceding
11 factors are varied. The cost factor information is
12 displayed on any of work stations 200, 202 and 204.
13 Mathematical algorithms known in the art are used in
14 determining the cost factor. In step 410, the cluster
15 scheduling program terminates and the overall process
16 implemented by master node 208 resumes at step 308.

17 The particular hierarchical segmentation and
18 template matching computer programs and algorithms
19 described in the foregoing description are examples of
20 suitable programs and algorithms that facilitate
21 realization and working of the invention. Thus, it is to
22 be understood that other suitable segmentation and
23 template matching programs may also be used as well.

24 The present invention provides many advantages and

- 1 benefits, such as:
- 2 a) elimination of the need for cultures;
- 3 b) provides for rapid and accurate identification
- 4 of pathogens, bacteria, infectious diseases and abnormal
- 5 cells;
- 6 c) allows separation of the image acquisition
- 7 subsystem from the image processing and identification
- 8 subsystem to allow remote operation under demanding
- 9 conditions;
- 10 d) uses multiple data transmission paths to take
- 11 advantage of the available communication systems;
- 12 e) uses a relatively low-cost parallel processing
- 13 computer system to achieve near real-time operation;
- 14 f) combats infectious diseases, reduces morbidity
- 15 and mortality, and provides high-level medicine to remote
- 16 areas of the nation and the world;
- 17 g) effects diagnosis of infectious diseases due to
- 18 bacteria, and detection of bacterial contamination of
- 19 foodstuffs;
- 20 h) subsystem 100a can be located in small
- 21 hospitals and clinics, particularly in rural or remote
- 22 areas such as Appalachia and Indian Reservations, as well
- 23 as in Third World countries with limited access to
- 24 healthcare facilities;

1 i) subsystem 100a can be located in large
2 slaughterhouses, meat and poultry processing facilities,
3 large dairy farms and other agribusinesses in order to
4 enable detection of bacteria before such meat, poultry
5 and dairy products are shipped to consumers; and

6 j) subsystem 100a can be located at research
7 laboratories, the Center for Disease Control, and
8 pharmaceutical manufacturers to aid in research and in
9 the development of new antibiotics.

10 Although the foregoing description is in terms of
11 the present invention being directed to the rapid
12 identification of pathogens, bacteria and abnormal cells,
13 the system and method of the present invention can be
14 used as a diagnostic radiology and imaging tool in the
15 medical and dental field. Specifically, the system and
16 method of the present invention can be configured to
17 analyze medical images such as images of soft tissue,
18 mammograms, x-rays (bone and dental), ultrasounds, MRI
19 images, and CAT scans. In such an embodiment, the
20 aforementioned images are segmented to generate regions
21 for identification in generally the same manner as the
22 digital microscope images described in the foregoing
23 description. Specifically, the image is transferred to
24 image processing system 190 wherein workstations 200,

1 202, and 204 are used to compress the images. In a
2 preferred embodiment, loss-less compression software
3 programs, known in the art, are used. Preferably, the
4 compression software is certified for use on medical
5 images. Suitable compression software is GZIP and BZIP2.
6 Other suitable compression software can be used. Next,
7 the compressed image is stored into file server image
8 repository 222. The compressed image is stored in
9 repository 222 and is subsequently retrieved so it can be
10 segmented and/or compared against another image, segment
11 or region. After the compressed image is retrieved from
12 repository 222, the compressed image is prepared for
13 segmentation using the recursive hierarchical
14 segmentation program described in the foregoing
15 description. Preferably, the aforementioned recursive
16 hierarchical segmentation program is performed on a
17 parallel computing platform as described in the foregoing
18 description (e.g. master node 208). As described
19 previously herein, the image segmentation process
20 comprises partitioning an image into sections or regions.
21 These regions may be subsequently associated with normal,
22 abnormal or deviations in various tissues, however, the
23 segmentation process simply gives generic labels to each
24 region. The regions consist of groups of multi-spectral

1 or hyper-spectral image pixels that have similar data
2 feature values. These data feature values may be the
3 multi-spectral or hyper-spectral data values themselves
4 and/or may be derivative features such as band ratios or
5 textural features. Simultaneously, regional images that
6 have been segmented into their sections or regions and
7 masked segmented images that have been labeled are stored
8 in repository 220. The images stored in repository 220
9 can be recalled by the scalable template matching program
10 , described in the foregoing description, for either
11 viewing or matching known or defined segmented regions
12 that have been associated with normal, abnormal or
13 deviations in the radiological images.

14 The principles, preferred embodiments and modes of
15 operation of the present invention have been described in
16 the foregoing specification. The invention which is
17 intended to be protected herein should not, however, be
18 construed as limited to the particular forms disclosed,
19 as these are to be regarded as illustrative rather than
20 restrictive. Variations in changes may be made by those
21 skilled in the art without departing from the spirit of
22 the invention. Accordingly, the foregoing detailed
23 description should be considered exemplary in nature and
24 not limited to the scope and spirit of the invention as

1 set forth in the attached claims.